Tracking and Characterization of NEO's

Using AMOS Ground-Based Optical Telescopes

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Both the mass and orbit must be known to assess the threat from a given NEO. The orbit and position define the velocity so the uncertainties in the momentum and energy are dominated by how accurately the mass can be estimated. The mass, in turn, is the product of the volume and density of the NEO. Because NEO reflectivity can vary from about 2 to 50%, simply measuring brightness and assuming reflectivity results in a diameter estimate with a factor of two uncertainty. This leads to a factor of eight uncertainty in the volume. Asteroid densities are believed to vary from about 2 to 7 g/cm^3. Adopting a mean density introduces another factor of two uncertainty into the mass. Thus, the total uncertainty in the momentum and impact energy, due to the individual uncertainties in the diameter and density, can be as large as a factor of sixteen. The taxonomic class of an asteroid can be determined from visual photometry. This constrains the mineralogy of the object and reduces the uncertainty in the density estimate. Size estimates based on visual photometry and infrared radiometry are accurate within 10%. We describe an observational program which uses the demonstrated capability at AMOS to obtain accurate astrometry necessary for orbit determination, photometry for classification, and the ongoing upgrades to the AMOS facility to provide the observations required to determine the physical parameters discussed above. These observations reduce the total mass uncertainty to about 50%.

Introduction

Physical characteristics of NEOs

Risk assessment of threat NEOs is hampered by a lack of knowledge regarding their physical properties, in particular their mass and composition. In order to assess the threat from a given NEO, one must know both its orbit and its mass. For a given velocity, the energy and momentum of an NEO is proportional to its mass, *i.e.*, to the product of its volume and density. In order to choose the appropriate mitigation strategy, knowledge of the NEO's composition (carbonaceous?, iron?), dynamics (spin rate and pole orientation), and structure (shape, cohesiveness) are also required.

We will estimate the mass uncertainties with and without knowledge of the size and taxonomic class of an NEO under the assumption that the NEO's are either asteroids or have surface reflectance and thermal properties similar to those of asteroids. We describe a program using the AMOS facilities to obtain astrometry for orbit determination and multicolor photometry for taxonomic classification. Future upgrade to provide infrared radiometry are explored.

NEO mass and composition

Because the reflectivity of an asteroid can vary from a few percent to as high as fifty percent, simply measuring its brightness and assuming a reflectivity results in a diameter estimate with about a factor of two uncertainty. This leads to a factor of eight uncertainty in its volume.

Asteroid densities are believed to vary from about 2 to 7 g/cm^3. Assuming a density of 3.5 g/cm^3, introduces another factor of two uncertainty into the mass. Thus, the total uncertainty in the impact energy and momentum, due to uncertainties in the diameter and density, can be as large as a factor of sixteen.

As was demonstrated in the Phillips Laboratory (GPOB)-supported IRAS Minor Planet Survey (Tedesco, 1992, 1994), asteroid diameters can be determined to within less than 10% uncertainty if both a visual brightness and a single thermal infrared flux are known. Additionally, if a taxonomic class can be determined, then the density can also be constrained. For example, the density of the "carbonaceous" classes is believed to be about 2.5 ± 0.5, that of the "stony" classes about 3.5 ± 0.5, and that of the "metallic" classes around 7 g/cm^3. Thus, assigning an asteroid to one of these three broad classes reduces the density uncertainty to about 15%. Hence, in cases where both the diameter and taxonomic class are known, the total uncertainty in the mass can be reduced to about 50%, *i.e.*, to about 3% of the uncertainty in the absence of such data.

The Phillips Laboratory program

Background

While many organizations have expressed an interest to participate in the discovery phase of PDI, few have proposed the requisite follow-up observations and no group has the unique combination of facilities and expertise to obtain accurate position measurements and to analyze and classify the objects discovered by means of observations at different wavelengths. The Geophysics (GP) and Lasers and Imaging (LI) Directorates have such facilities, expertise, and interest to do such follow-up observations and analyses.

The Backgrounds Branch (GPOB) in the Optical Environment Division of the Geophysics Directorate, Phillips Laboratory has a mission to determine the general nature and detailed character of the backgrounds against which an Air Force electro-optical system must operate. This is accomplished by conducting field measurements and surveys of the transmission and emission of the atmosphere as well and the radiance from the celestial background. Under the celestial background effort, the branch has long been interested in asteroids as a major component. Because of their low reflectivity and high infrared emissivity, asteroids are a source of infrared clutter and false targets of interest to the midcourse surveillance community. The PL/GP predecessor organization, AFCRL, provided the first realistic predictions of the magnitude of the asteroid problem for a space based infrared sensor (Murdock, 1973). This analysis was concurrent with the first infrared detections and limited survey of asteroids from space by the AFCRL/AFGL rocket borne sky surveys (these are unpublished, reference is given to the later article by LeVan and Price, 1984). PL/GP later sponsored the retrieval of archived asteroid measurements obtained by a NASA survey satellite (IRAS) and had them reanalyzed to produce the currently used database of asteroid sizes. These analyses have been codified into a model which has been incorporated into a Celestial Background Scene descriptor which provides the position and brightness of any of the known, numbered asteroids, for a specified date and predicts the statistical distribution for the fainter, as yet to be discovered, objects. The GP interest in the planetary defense initiative is a natural consequence of previous experience and contribution to the overall objective of understanding the distinguishing factors which separate the asteroids into different populations.

Analysis sponsored by GP has led to the ability to accurately determine the diameter and taxonomic class of an asteroid. As noted above, this is important to planetary defense because one must know both the orbit and size in order to assess the threat from a given NEO.

GP is engaged in or associated with current efforts to detect and classify asteroids. The astronomy experiments on BMDO's Midcourse Space Experiment are the responsibility of the GP principal investigator. There are two of these experiments to measure asteroids: One is to obtain the ultraviolet through infrared multicolor observations necessary to classify and determine the physical parameters of selected known objects; another is a target of opportunity experiment specifically for follow-up characterization of NEOs. Another experiment uses the European Space Agency's Infrared Space Observatory (ISO) to discover faint asteroids. The NEO observations directly support the PDI objectives. Observations of main-belt asteroids indirectly support PDI through analysis of the characteristics of the general population of asteroids with NEOs as a defined sub-class. The GP interest in the Planetary Defense Initiative is a natural consequence of previous experience and contribution to the overall objective of understanding the distinguishing factors which separate the asteroids into different populations.

The mission of Phillips Laboratory's Air Force Maui Optical Station (AMOS), part of the Maui Space Surveillance Site (MSSS), is to conduct research and development of new and evolving electro-optical sensors, as well as to provide support for operational missions defined by US and AF Space Command. In addition, AMOS also provides experiment support to a wide variety of military and civilian organizations in diverse fields. This support has included the Strategic Defense Initiative Organization (SDIO) and its successor, the Ballistic Missile Defense Organization (BMDO), the National Aeronautics and Space Administration (NASA), the Jet Propulsion Laboratory (JPL), and many universities. Typical AMOS visiting experiments include:

- support for tactical and strategic missile launches out of both Vandenberg and Kauai
- detection and tracking of orbital debris
- observations of shuttle and satellite special operations
- atmospheric physics
- space sciences and astronomy

Recent and historical experience in all of the above missions has given PL/LIMM expertise in those areas necessary to support the PDI in general, and to provide PL/GPOB with the data to derive the physical characteristics of NEOs.

AMOS telescopes include a 1.6 meter telescope, an 80 centimeter Beam/Director Tracker, and a 60 centimeter Laser Beam Director. The Maui Optical Tracking and Identification Facility (MOTIF) includes twin 1.2 meter telescopes on a common mount. The JPL CCD camera, currently used in support of NEO observations, is mounted on one of the 1.2 meter telescopes. An automated filter wheel containing Johnson U, B, V, and R filters plus an Eight-Color Asteroid System x filter (*cf.*, Tedesco, *et al.*, 1982) will replace the single-filter holder in the JPL CCD camera in July 1995. GEODSS includes two main 1 meter telescopes and an auxiliary 40 centimeter telescope. A major upgrade to AMOS will be the Advanced Electro-Optical System (AEOS), a 3.67 meter telescope scheduled for first light in 1997. AEOS will have seven coudè rooms for various experiments, as well as bent Cassegrain positions located on the mount itself.

Sensors associated with these telescopes include a wide range of detectors and visible through infrared imaging arrays. The 1.6 meter telescope has a Compensated Imaging System which has been operational since 1982. The new AEOS will also incorporate an adaptive optics system for atmospheric turbulence compensation. Recently completed is the AMOS Daytime Optical Near Infrared Imaging System (ADONIS), capable of extending the AMOS imaging capabilities to 24 hours per day. These adaptive optics systems allow AMOS to take photographs with outstanding clarity, close to the diffraction limit, in spite of the severe problems of dealing with atmospheric turbulence.

GPOB and LIMM contributions to PDI will be along the following lines:

- LIMM will do timely follow-up astrometry and multi-color photometry subsequent to discovery of a Near Earth Object. This capability is the result of the unique environment at the MSSS, which must respond rapidly to short notice tasking by the Air Force. This rapid response is not possible for most civilian observatories using large optical telescopes. LIMM is active in the search for, and follow up of, NEOs, routinely sending astrometric and photometric data to both the Jet Propulsion Laboratory (JPL) as well as to Dr. Brian Marsden of the Minor Planet Center.
- GPOB has the experience and expertise to interpret the photometry and radiometry and accurately derive the physical characteristics of the object.

Orbits

LIMM has used the JPL camera in a single visible spectral band on the 1.2 m telescope for more than a year in support of the JPL visiting experiment. Rapid and efficient procedures have been developed to acquire and track the designated NEOs. LIMM is obtaining positional accuracies of less than 1 arc second, using the Hubble Guide Star Catalog and the astrometry routines with the astronomical software package IRAF. The photometry is calibrated to about 2 percent, allowing reliable determination of light variations with time.

Taxonomy

AMOS will accurately measure the astrometric positions of NEOs discovered in the search programs and obtain multicolor photometry on them. We will analyze the multicolor photometry to ascertain the taxonomic classification, and to improve the accuracy in estimating the size and mass of the object. This will be a collaborative effort between the Air Force Phillips Laboratory's Air Force Maui Optical Site (Directorate LIMM) and the Geophysics Directorate (GPOB).

Taxonomic classes can be determined, to first-order, from multi-color photometry alone. As shown by Tedesco *et al.* (1989), measurements in the U, V, and x filters, plus an albedo determined from radiometric or polarimetric observations, results in a classification into one of a dozen or so broad classes.

Of the approximately 300 NEOs discovered to date about 50 have multi-color photometry and about 40 measured diameters and albedos. The reason for the small fraction of NEOs with physical observations is the difficulty in obtaining the requisite measurements. Unless an observer interested in NEOs and fortuitously at a telescope equipped with the appropriate instrumentation, during, or within a month or so, of the discovery it is not possible to obtain an observation until the NEO once again makes a close approach to the Earth. This very often does not happen for many years. Even if such an observer is ready to make the observation it often happens that, either the orbit is not yet known accurately enough to find the object, or poor weather, result in no observations being obtained. This is true of the astrometric follow-up as well. The AMOS program is designed to overcome these obstacles.

Sizes

Radiometric observations at 10 μm, using the AMOS 1.6 m telescope will, when combined with the visual photometry from the 1.2 m telescope, provide the data necessary to determine the diameter and albedo.

The AMOS NEO program

The AMOS program is unique in that there are multiple co-located telescopes each performing a specialized, coordinated function.

The tasks necessary to fulfill the PDI charter may be summarized as follows:

1) Search and Discovery
2) Astrometric Follow-up
3) Physical Characterization
    a) visual photometry/spectroscopy
    b) infrared photometry and/or polarimetry

The AMOS program is the only one with all of the following coordinated systems:

1) Search and Discovery
    CCD-equipped Maui 1 m GEODSS search instrument
2) Astrometric Follow-up
    MOTIF 1.2 m telescope with CCD camera (orbit refinement)
3) Physical Characterization
    a) visual photometry/spectroscopy
        Multi-color (U, V, x) photometry with the MOTIF 1.2 m (taxonomic classification)
    b) infrared photometry and/or polarimetry
        IR (10 μm) capability with the MOTIF 1.6 m and, eventually, the AEOS 3.67 m (size and albedo)

Phillips Laboratory Development Strategy

Current Capabilities (mid-1995)

1 m Maui GEODSS for detection. (JPL NEAT program.)

MOTIF 1.2 m telescopes for follow-up. (800x800 JPL CCD camera with U, V, and x filters.)

Near-Term Plan (FY 1997)

Replace the JPL CCD camera on the 1.2 m telescope with a three-channel CCD camera for simultaneous U, V, and x photometry.

Acquire a sensitive VLWIR (10 μm) radiometer for the 1.6 m telescope.

Long-Term Goals

Expand follow-up observations by AMOS to other Phillips Laboratory sites at Malabar, Florida and Albuquerque, New Mexico.

Enhance follow-up observations at AMOS through the use of larger aperture telescopes (*e.g.*, 3.67 m AEOS) and new instrumentation (*e. g.*, a polarimeter).

Summary

The program described here has already begun to produce results. LIMM routinely sends astrometric data to Dr. Brian Marsden of the Minor Planet Center, and AMOS was commended in a recent NASA report for the first follow-up of a Near Earth Object by a military telescope.

In the process of obtaining follow-up observations, uncataloged objects are routinely detected in the instrument field of view. Asteroid 1995KB, for example, was discovered at AMOS during routine operations.

The program will enter phase 2 in July 1995 with the addition of a multi-color photometry capability.

References

LeVan, P.D, and Price, S. D., "85-μm Fluxes from Asteroids: 2 Pallas, 7 Iris, 15 Eunomia and 45 Eugenia," *Icarus*, **57**, 35-41 (1984)

Murdock, T.L., "The Contribution of Asteroids to Infrared Astronomical Sky Surveys," AFCRL-TR-73-0154 (1973).

Tedesco, E. F., Tholen, D. J., and Zellner, B. "The eight-color asteroid survey: Standard stars", *Astron. J.*, **87**, 1585–1592. (1982).

Tedesco, E. F., Williams, J. G., Matson, D. L., Veeder, G. J., Gradie, J. C., and Lebofsky, L. A., "A three-parameter asteroid taxonomy", *Astron. J.*, **97**, 580–606 (1989).

Tedesco, E. F., *The IRAS Minor Planet Survey*, Phillips Laboratory, Hanscom Air Force Base, MA, PL-TR-92-2049 (1992).

Tedesco, E. F., "Asteroid albedos and diameters", In *Asteroids, Comets, Meteors, 1993*, A. Milani *et al.*, eds., pp. 55–74, Kluwer Academic Publishers, Dordrecht/Boston/London (1994).